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Abstract The Atmospheric Release Advisory Capability (ARAC), located at Lawrence Livermore National Laboratory has embarked on a multi-year modernization effort that began over two years ago is now well underway with full completion expected by the year 2000. The modernization involves a new computer system, improved three-dimensional diagnostic flow and atmospheric dispersion models, and a completely new mesoscale prognostic atmospheric modeling capability. Terrain representation in the atmospheric transport flow and dispersion models will be continuous rather than the block-terrain representation in the earlier models. A UNIX-based distributed computing architecture will be the underlying framework for the 3-D visualization tools, interactive graphical user interface applications, communications software, file management, database management, and modeling environment.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48.

Introduction The Atmospheric Release Advisory Capability (ARAC), located at the Lawrence Livermore National Laboratory, was developed for the US Departments of Energy and Defense. Its purpose is to provide in real-time, to emergency responders, the downwind consequences from the release of radiological (and other hazardous materials) into the atmosphere whenever and wherever the US government deems necessary. Over the past 20 years, ARAC has provided consequence assessments for more than 70 hazardous events. We have applied our capability to diverse real world releases such as radiological (e.g. Chernobyl and Three Mile Island NPP accidents), toxic chemical (e.g. Richmond, CA sulfuric acid cloud), volcanic ash (e.g. Mt. Pinatubo), and smoke (e.g. Kuwait oil well fires).⁽¹⁾

The present ARAC technology has evolved over the past 20-years through two generations of system architectures and with only incremental improvements in our diagnostic wind field and dispersion models. Two years ago (1994), we began a third and much larger modernization program to both advance our system architecture and to upgrade the physics structure in our diagnostic wind and dispersion models, and to integrate mesoscale prognostic wind models into our capability. The existing architecture, which we call ARAC-2, is a 15-year old technology that is now difficult to maintain as a viable capability to fully address the problems of today. The new ARAC-3 capability will provide portability to our system so that it will be computer-platform-independent, a necessity in today's dynamically changing environment of computer hardware and operating system technology.

The ARAC Program emergency operation center and staff moved into a newly completed building in January 1996. This facility, called the National Atmospheric Release Advisory Center (NARAC), was built to house ARAC by the Department of Energy.

Models The diagnostic atmospheric wind field and dispersion models have served us well for the past 20 years. We have come to understand the strengths and weakness of our models during this period. The strengths we will retain while the weaknesses we have plans to correct. We have also come to recognize the importance of expanding our suite of models to include mesoscale prognostic models which can provide high resolution meteorological information for situations where observational data are unavailable.

Model grid and surface representation The current ARAC diagnostic wind flow and dispersion models employ a uniform grid resolution in both the horizontal and vertical dimensions, and use a "block" representation of the terrain. This stair-step representation restricts us to a rather crude description of the terrain of interest. In the new system, the block terrain representation is replaced with a continuous representation of the terrain. The grid structure of the new system is based on a terrain-following coordinate system and contains the option of varying the grid resolution in both the horizontal and vertical dimensions. This representation will not only give more realism to the models, but will eliminate numerical problems associated with wind flow and dispersion in artificially stepped terrain, allow for finer resolution gridding to be used when required, and will be compatible with the continuous terrain representation in the companion atmospheric prognostic models.

Dispersion model As part of our modernization effort, we have already implemented improved diffusion algorithms in our Lagrangian particle transport and diffusion model. Previously this code used a hybrid Gaussian and gradient diffusion scheme. For point sources and sub-grid scale area sources, Gaussian diffusion was used until the size of the initial cloud increased by dispersion to fill one or more grid cells, and then gradient diffusion was applied. Our new algorithm is a Monte Carlo approach to the diffusion process using the random displacement method (RDM).⁽²⁾ The RDM diffusion is fully grid cell independent and eliminates grid resolution difficulties associated with typical gradient diffusion approaches when point sources are modeled.

We currently use a rectangular nested grid structure of up to four inner nests to sample the cloud of Lagrangian marker particles close in to the source. The new dispersion model will allow a high resolution sampling near the source with an almost arbitrary choice of ever increasing cell sizes as one moves away from the source location. This will eliminate discontinuities in the plume edges that often occur with the nested grid sampling because of the discrete boundaries of each nest.

We have also implemented a "hybrid particle" version of our dispersion model. Earlier versions of our code were limited to dispersing up to nine radionuclides in any one model run. The hybrid particle version will disperse a complete and unlimited mix of radionuclides, while not only allowing the radioactive decay of each radionuclide in the mix during dispersion and deposition, but will spawn all the daughter products and add these to the mix during the model run. This new capability greatly enhances our flexibility in dealing with the mix of radionuclides that may be released from a nuclear power plant accident.

Diagnostic wind field model The new diagnostic wind field model will have an improved capability to assimilate meteorological data that is obtained from multiple sources (i.e. surface, rawinsonde, multi-level meteorological tower, SODAR, LIDAR, microwave profiler, and gridded). As with the new dispersion model, the new diagnostic wind field model will use a terrain-following coordinate system which provides continuous representation of the terrain. The variable resolution of the new grid will have a capability to increase the resolution of the wind field over meteorological mesonets that are imbedded in regions of widely spaced meteorological observations. It will also allow us to incorporate multi-level tower, SODAR, LIDAR, and microwave profiler data in the vertical dimension while modeling a deep lower atmosphere. This new model will also improve our capability for maintaining the integrity of the input vector winds (speed and direction) via a new, finite-element-based, mass-consistent adjustment process.

Prognostic models As part of the modernization effort, we are adapting and integrating the US. Navy's operational prognostic models Navy Operational Regional Atmospheric Prediction System (NORAPS) and the follow-up Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS) into ARAC's operational architecture. Our near-term objective for these mesoscale prognostic models is to be able to rapidly generate detailed regional atmospheric flow fields in space and time anywhere worldwide for emergency response assessments. Longer term objectives are to generate detailed cloud and precipitation fields that may impact the transport and deposition of hazardous materials.

The NORAPS model is a primitive equation hydrostatic code with a variety of physics modules. It has a 3-grid nesting capability and can ingest observation data from data sources around the world. The LLNL version of NORAPS is capable of generating initial gridded fields from the US Navy's global (NOGAPS) and regional (NORAPS) forecast products, and also from the NOAA Environmental Prediction Center's (formerly NMC) global AVN and regional ETA forecast products. We expect to obtain the non-hydrostatic COAMPS model from the US Navy by the end of the 1996 calendar year which will extend our mesoscale forecast capabilities from regional to local scales. Our current forecasts with the NORAPS model are typically based on grid resolutions of 36, 12, and 4 km. We have seen that in near coastal environments where the micro-climates differ over short distances, it may be necessary to run the model with even finer resolutions in order to capture the character of the temperature, precipitation, and wind fields.

Integration of the prognostic model into an operational emergency system poses a formidable challenge with respect to generating advisory products in a real-time mode. The reason is that forecast models typically require a significant amount of computational time relative to diagnostic models. Our strategy for deploying prognostic models in a real-time mode is to generate 48hr limited area forecasts at 15 km or less resolution, once daily, for two regions encompassing most of the sites supported by ARAC (e.g., domains centered over the East and West Coasts of the U.S.). The meteorological fields will be

updated once every 24 hours based on the most current global analysis and will be used as gridded data for the diagnostic models. If an emergency occurs outside of the forecasted domains, initial response will be rendered by the diagnostic models using local observational data and gridded data from available global forecasts, such as from NOGAPS or AVN forecasts (both containing about 1° grid resolution information). The NORAPS forecast domain will be relocated to the region of interest and the prognostic model will begin computations, at finer resolutions, with the most recent global analysis and forecasts as initial and boundary conditions. Our eventual goal is to generate an initial prognostic emergency response calculation of a 24hr forecast within 4 hours of the start of the event and subsequent forecasts in 2 to 3 hours. In order to achieve the speedup required of the prognostic model, we are actively seeking ways of reducing the computational time via implementation of multiprocessing techniques in conjunction with coding modifications to increase the computational efficiency of the model.

One of our first tests of the prognostic wind data is to drive the "block" terrain version of our diagnostic wind field and dispersion models with the forecasted grids from the NORAPS model runs. In the new ARAC system, the new dispersion model will be driven directly from the forecast grids or indirectly by passing the forecast grids to the diagnostic wind field model. The diagnostic model ingests both the regional gridded data for NORAPS as well as the local on-site observational data and, with appropriate blending, generate high-resolution wind fields that are properly mass-adjusted relative to the continuous terrain.

Supporting Software and Databases A new computer software system, the ARAC-3 System, is being developed to provide many improved emergency response capabilities to the ARAC Program. The ARAC-3 System is a complex integrated system using many new computer technologies and consisting of a large number of components that must interact in a coherent fashion. While the atmospheric dispersion models are the backbone of ARAC, the software system and environment that surrounds these models is critical to ARAC's ability to respond effectively and efficiently to emergencies and exercises. The entire structure of existing ARAC-2 supporting software that includes model parameters, the model execution framework, the automation processes, the data acquisition and communication processes, the database interfaces and file structures, and the visualization tools are being modernized under the new ARAC-3 System. The computer languages of choice for the models is FORTRAN 90 while the choice for the supporting software is C++. The new system employs the widely-used UNIX operating system to allow for transportability on UNIX-based platforms and netCDF data format for portability and standardized data protocol.

A clear priority for an emergency response system is ease of organizing the specification of an assessment (model) sequence and automated execution of necessary functionality. The system must manage, display, and analyze the vast amounts of data required by ARAC, as well as manage the results generated by the models. Therefore, the manner in which relevant information is stored forms a central component of the ARAC-3 System. This relevant information describes a particular release or set of releases, the metadata (meteorological data) related to that situation, the land surface surrounding the incident, model input parameters, etc. It is the responsibility of the system to unify all the interdependent sets of information. It must provide quick and easy access to and control of all critical information (accident time, location, source description(s), terrain information, etc.).

Model parameters A major function of the ARAC-3 system is the automated creation of a set of consistent, intelligent parameters for the atmospheric models. These parameters describe the source location, type of release, the geometry of the release, the types of plots that will be generated, the dose pathways, final units, emergency action concentration levels, etc. some are meteorologically dependent, others are agency dependent. These parameters may be edited using a library of possible algorithms for the calculation of initial values.

Model execution framework The execution and control of the ARAC-3 atmospheric models is performed by an extensible model execution framework. This framework is responsible for controlling the execution of the models and a myriad of other functions. It will allow the execution of the models and other applications to be distributed to a variety of UNIX computers, allowing each application to take advantage of the computer best suited to meet its needs. For example, the models will be able to utilize the speed of a multi-processing computer, while the 3D visualization applications will utilize the graphics display capabilities of powerful workstations.

Automation The complete elimination of manual steps is another requirement of ARAC's emergency response system. Thus a series of automatic actions must be performed based on the information stored about a particular event. The system is able to generate an initial calculation in a "hands-off" response mode (i.e. no human intervention is required) and in a TAHOE (Totally Automated Hands Off Exercise) mode. The former is the foundation of ARAC's rapid initial response while the latter allows ARAC's remote sites to practice exercise responses with ARAC plots as frequently as they wish. These steps include activities such as activating the execution of the model, obtaining metdata, and producing final plots. Part of the model execution process determines what models to execute, on what computer system to execute the models, where to place the output, and how to monitor the modeling process.

Acquisition and communications The area of data acquisition and communications involves obtaining data from outside sources as well as communicating with ARAC's remote site system. The ARAC-3 System will communicate with remote ARAC site systems through several network communication paths (dial-up, DOE EMS T1, and private leased lines). The standard communication with ARAC's remote site system involves transferring problem definition information, metdata, field measurements, model products, and mail. Periodic communication with the sites is required to maintain metdata acquisition from the meteorological towers, upgrade software and hardware, maintain up-to-date information on the individual site's environment, and track any problems with the system. Other remote communications include FAX communications between the sites/clients and the ARAC-3 System, and connecting with an outside news wire service. The acquisition of metdata involves acquiring data from AFGWC (Air Force Global Weather Center), FNMOC (Fleet Numeric Meteorology and Oceanography Center), DDP (Domestic Data Plus), ARAC remote site systems, meteorological towers, AccuWeather, McIDAS, and Internet. This metdata includes both observational data and gridded data. New sources of metdata as well as new types of metdata will be acquired in the future.

Databases A rich collection of data is required to satisfy the expanded scope and capabilities of ARAC-3. The source of that data consists of both external and internal data. External data includes world-wide weather information and cartographic suites. Internal data includes information that implements the knowledge base of an emergency response system as well as data required to operate the system models. Virtually all data stored within the ARAC-3 system will be accessed and archived through a collection of databases. Exploiting database technology to organize the diverse data population will help in simplifying application program access to the varied information base that will be required to make a model prediction. Because much of the design of the non-model components of the system will be based on the object oriented paradigm, an object-oriented database management system will be used to manage this information.

Types of data to be stored in the database are: metdata, land surface geodata (geodata used directly in model calculations, e.g., elevation data), reference geodata [base map information, gazetteer data (geographic names), demographic data, etc., which is used to orient assessors and users geographically], chemical data, and radionuclide dose factor information. Metdata consists of both observational and gridded data. Global geographic data is needed in order to respond to events anywhere in the world on

domains ranging from ~2-20,000 km. Land surface geo-databases include: ETOPO5, DMA Level I DTED, ARAC 500m & 125m data, USGS DEM data, USGS 1:250,000 Land use/Land cover data, Soil Conservation Service STATSGO soil data and bi-weekly AVHRR Normalized Difference Vegetation Index (NDVI) data. Reference geo-databases include: NCAR Global & US Maps, USGS DLG data, DMA DCW, Census TIGER data, DMA ADRG, hand digitized site facility maps and local regions, USGS Geographic Names Information System, DMA Gazetteer data, Census Bureau population data (or equivalent value-added databases). Sources for the chemical database include: CAMEO, ALOHA, DIPPR, and ERPGs.

Visualization and Other Tools A suite of tools will provide access to the ARAC-3 resources. The goal of these tools is to provide an integrated decision-making capability. This involves simultaneous visualization of multiple data types (terrain, map features, observed metadata variables, analyzed metadata variables), availability of defaults which minimize re-typing of information (e.g., selection of updated site-input Questionnaire entries rather than having to re-enter these values), graphical methods for user input, continual monitoring of processes, etc. Tools will be provided to manage both the standard system administrative functions as well as those unique to an emergency response. Some of these are provided as part of the operating system and some are specialized tools. The standard system administrative tasks involve daily, weekly, and monthly backups of both the user and system disks, disk optimization, performance monitoring, accounting information, maintaining both classified and non-classified systems, and providing security on the systems as well as individual elements of the system.

Conclusion We have undertaken a very large and ambitious modernization program to bring the ARAC system of models, supporting software, databases and visualization tools up to the state of today's technology after approximately 15 years of only small incremental improvements. We expect the base modernization program to be fully implemented into our production environment by the year 2000. We are nearly on target, having already demonstrated initial versions of our new models and the underlying framework or architecture of the ARAC-3 system.

References

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